2. PHYSIOGRAPHY AND CLIMATE

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2.1 Physiography

Physiography is used here in its original connotation to mean the integration of landform, soils and vegetation as landscape units. The Abydos-Woodstock Reserve lies across the junction of two distinct physiographic units, the Gorge Fold Ranges and the Abydos Plain (Figure 1.1B).

The western edge of linear to arcuate parallel belts of steeply folded stony razorback ridges of the Fold Range unit sharply abuts the Abydos unit of undulating red earth plains developed on granites and sedimentary deposits. The two units are linked by a faintly inclined pediment zone (outwash plain) of varying width which extends outwards from the base of the fold ranges (Plate 1). On the plains are scattered or grouped small inselberg blockpile tor and dome residuals (Plates 3-5, Figure 2.2). Dykes of basic igneous rock or quartz form long lines which criss-cross the landscapes of both units. The dykes outcrop as rocky ridges, walls or cone hill remnants whilst others have been weathered to or below their surroundings.

The Reserve area forms a point of divergence, source area, of the three major rivers which drain the region. The Yule, Turner, and Shaw branch of the De Grey River which drains the greater part of the Fold Range unit (Figure 1.1D). These have mainly dendritic drainage patterns, except in the fold ranges where it is trellis-form, with broad shallow sand-filled braided beds, relatively straight courses and anastomosing channels. All drainage in the region is seasonal to episodic and exoreic, the surface flow is of short duration from intense high rainfall occurrences. Rock basins and scour pools retain water into the dry season, and a few through until the next significant rains (Plate 23).

Abydos Plains

This unit is triangular in shape, 300 km at its widest along the coast between Cape Preston and the De Grey Delta. It rises gently inland to the 350 m contour where it meets the Chichester Range 200 km to the south and the Gorge Fold Range unit bounding its eastern side where the Reserve is situated (Figure 1.1B).

The plain is flattest towards the coast below the 150 m contour which lies some 80 km inland. Above this contour through the Reserve area it is a gently undulating convex-concave plain covered by short 3 to 4 m high scrub dominated by thorny Ranji wattle (*Acacia pyrifolia*) and soft spinifex savanna on neutral to alkaline gradational and duplex red earths (Figure 4.5; Plates 41-46). A feature of the plainsland are large bare termite hills up to 2.5 m in height built by *Nasutitermes triodiae* (Plates 42-44). This landscape is traversed by a dendritic sand creek drainage systems with broad braided linear to faintly sinuous, courses supporting bands of 10 to 12 m tall river gum and cadjeput riverine woodland (Plates 18-20).

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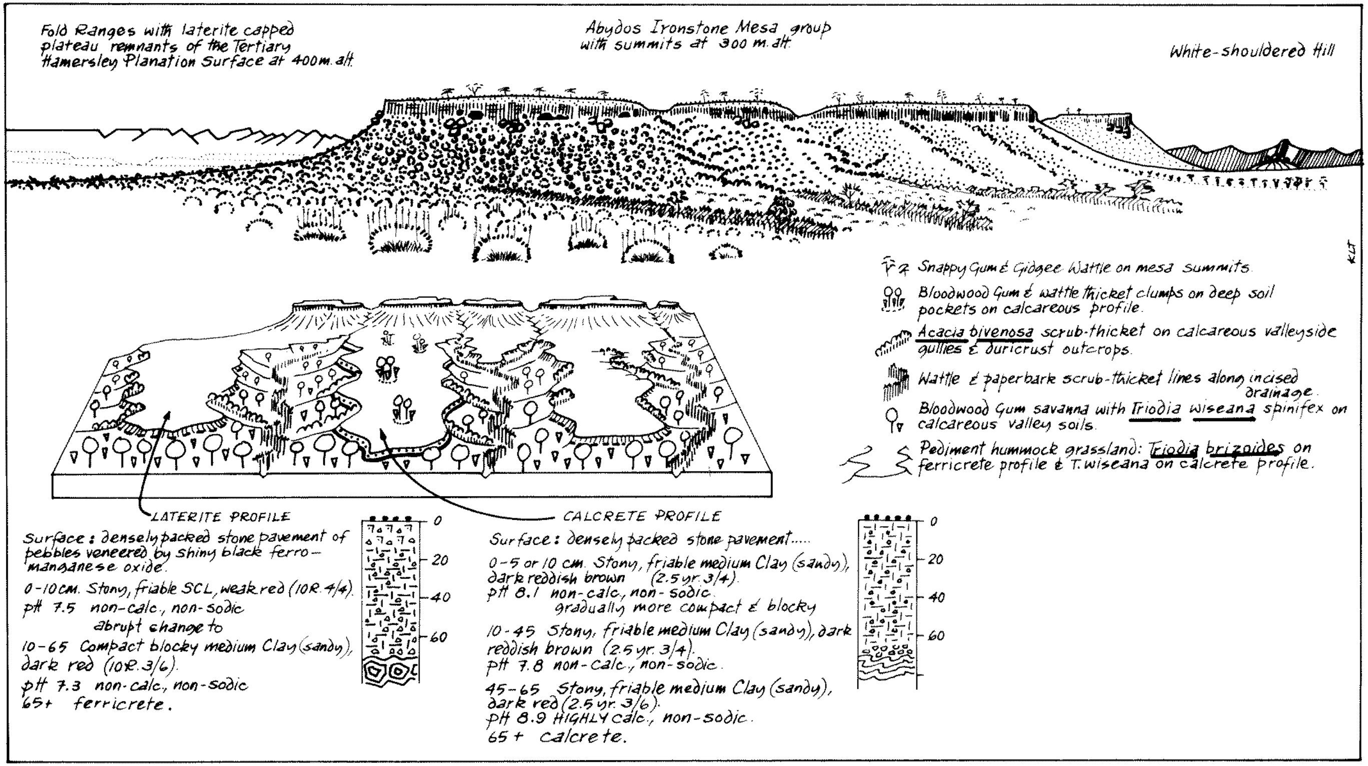

Figure 2.1 Junction of contrasting landforms in the source area of the Turner River catchment: where isolated mesas surrounded by broad incised pediments abut upland fold ranges and the granite plains with their dome and tor residuals. The Abydos mesas viewed from the N.W.

Radiating downslope from near the crests of plainsland convexities from which they rise are a special kind of remnant planation drainage feature referred to as a "dambo". Dambos are unincised seasonally waterlogged drainage lines on gently inclined planar and undulating surfaces, and occur as relics on plateaux. As extremely shallow even floored drainage depressions their presence is most clearly defined by linear treeless grassland gaps in a greater wooded grassland cover. In the Reserve they are remnant on the higher older granite plain surfaces and originate from the vicinity of dome and tor outcrops (Figure 4.8; Plates 47-49).

The isolated granite blockpile tors on the plains are generally between 5 and 30 m in height from their base, and the domes are slightly higher from 20 to 80 m in height. Closely grouped large granite domes with blockpiles on their summits occur chiefly between the NW of the Reserve and mounts Tinstone and Francisco. Widely scattered to grouped blockpile tors occur chiefly in the centre, and large smooth bare rock domes without summit tors occur in the SE of the Reserve. For details of dome and tor development in the tropics refer to Thomas (1974) for examples. The granite residuals support a sparse though distinct small tree flora including several rock figs (Figure 2.2; Plates 3-5, 57).

A few razorbacks of ultrabasic rocks and chert of the Fold Range unit occur as isolated outliers on the plain. A line of ironstone mesas which rise 40 m above the surrounding pediment form a distinct landscape in the NE of the Reserve (Figure 2.1, Plate 6). The very broad pediment zone here has been dissected by creek drainage leaving inclined planar interfluves and badlands type gullies which have exposed subsoil calcretes on the valley sides and bottoms. The interfluves are stony red clays mantled by a compact stone pavement or gibber of pebbles coated by a shiny black desert varnish. Where soils are calcareous the cover is chiefly a savanna of bloodwood gum and a grasslayer dominated solely by the hard dark green spinifex *T. wiseana* (Figure 4.3; Plates 30, 34). Non-calcareous soils support a pure grassland of glaucous hard spinifex *T. brizoides*. The creeklines and calcrete outcrops are covered in a dense wattle scrub cover (Plate 22).

The bottomlands in this unit comprises alluvial flats, calcrete terraces and benches, stream channels, sand splay deposits, gravels and calcrete strew from truncated soils, floodplain alluvia and unincised flat drainage lines which merge gradually upslope with the convexities. Old river flat fines deposits are calcareous sodic clays covered by short spine-leaved spinifex grassland of *Triodia secunda* (Plate 50). Present day alluvia of floodplains marginal to the creeks are brown clayey sands supporting dense stands of *Acacia trachycarpa* a wattle with peeling "mini-richi" type bark (Plate 21). Residual bottomland calcretes form terraces and small mesas covered by a pure spinifex grass sward with or without an overstorey of bloodwood gum trees or low tea-tree scrub (Plate 31).

Gorge Fold Ranges

This unit is a fold complex exhibiting a layered succession of lower ultrabasic and basic rocks, volcanic and intrusive rocks and upper metamorphosed sediments of banded ironstones, mudstones, sandstones and abundant cherts. These were strongly folded into parallel belts of ridges and troughs and erosion has left the vertically upturned beds as swarms of razorback ridges which rise abruptly 30 to 80 m high above their bases (Plates 1, 2, 16, 59, 60). Amongst these ridges are a number of plateaux with Tertiary laterite remnants of the Hamersley Planation Surface on their summits which lie between 400 and 520 m altitude. The plateaux rise from 80 to 170 m above their base. The largest of these is the Soansville Plateau on the eastern border of the Reserve. It is edged by a cliffed scarp 60 to 100 m in height, where caves, overhangs, boulder scree, narrow ravines, waterfalls and plungepools occur (Figure 2.2; Plates 7-17).

Hill soils vary from skeletal stony rubble to deeper alkaline stony red sandy clay loams which support two kinds of spinifex hummock grassland depending on the presence or absence of lime, and scattered groves of 6 to 10 m tall Snappy Gum hill savanna (Figures 4.4, 4.9; Plates 35-40).

Drainage patterns have been inherited by superimposition from the now mostly extinct Tertiary Planation Surface that overlay the present landscapes (Hickman & Lipple 1978). Although these cut across the various rock types irrespective of their differing grades of hardness, there is a strongly developed trellis drainage which fits the fold pattern of parallel ridges and valleys and the resultant jointing.

The rocky creeks with narrow riverbank alluvium are lined with 10 to 12 m high coolibah gum trees and/or dense low wattle scrub and paperbark shrub thickets (Plate 20). The valley sides are formed by hillslope colluvium with old river terraces of calcretes, cobbles and gravels. Deeply incised rocky sections alternate with broad saline clay flats where overbank fines deposits have accumulated.

2.2 Climate

Broken long term weather records are available from Abydos and Woodstock stations that now form part of the Reserve area. These are supplemented by the much longer and more complete weather data records from Marble Bar which lies 70 km ENE of the Reserve boundary. These data are representative of the zone 100 to 200 km inland of the coast in which both Marble Bar and the Reserve occur.

Classification

The Pilbara region has a tropical arid continental climate with a narrow maritime zone along the coast that is influenced by marine air and advective sea breezes. The western coastal margin of the region has a winter rain regime changing eastwards inland and up the coast to an overlap zone with bimodal rain peaks thence into the late summer-autumn peak of the northern Pilbara.

In a world classification of climates using various parameters and indices the northern Pilbara falls within the following systems:

(a) Köppen's BSh type (arid climate with summer rain and winter dry season with year round dry and hot conditions) (Köppen-Geiger System, revised by Geiger & Phol 1953).

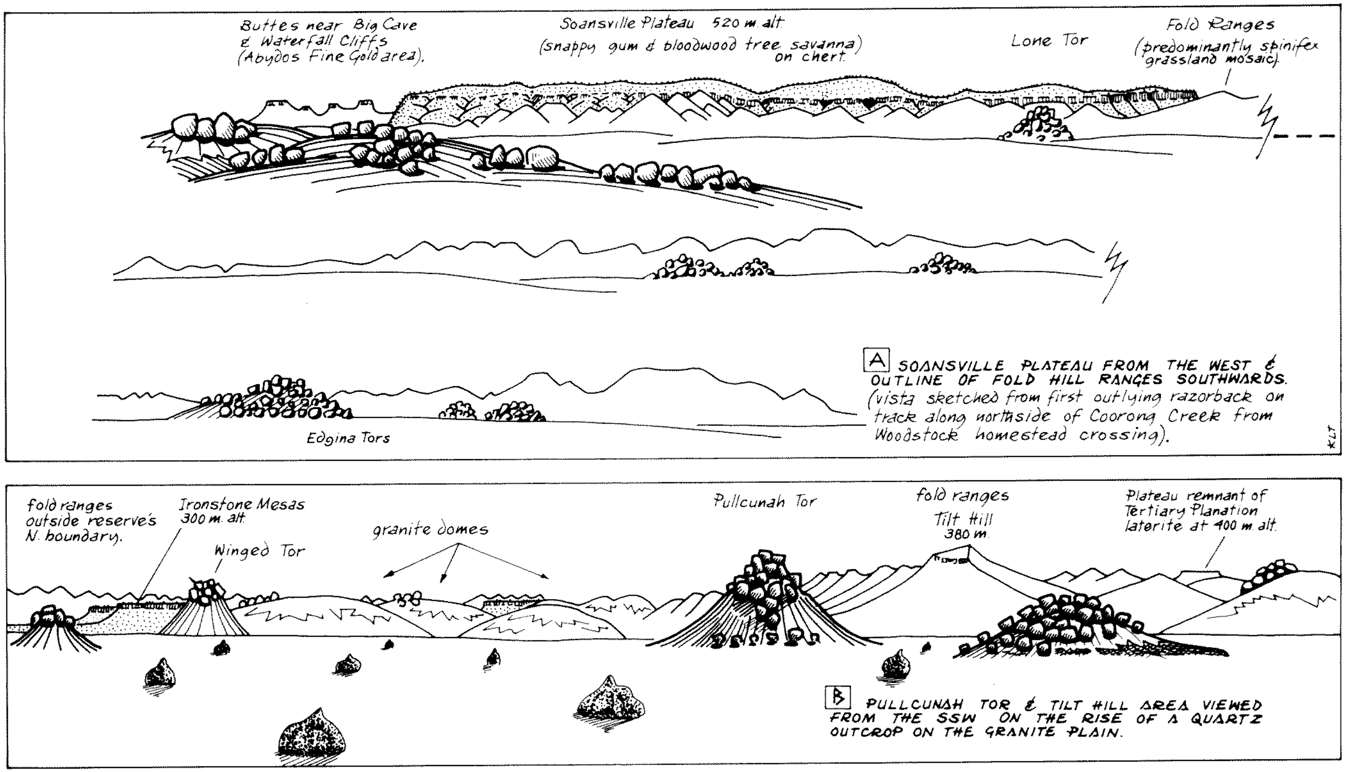

Figure 2.2 Landform diversity and characteristics of the two major physiographic units where granite plains with residual blockpile tors abut uplands of steeply folded hill ranges.

(b) Miller's (1953) Hot tropical continental, monsoon variety (A3m type).

(c) Holdridge's (1947, 1967) Arid tropical thorn woodland Life Zone.

(d) De Martonne's Aridity Index (P/T + 10).

The Arid Zone in the tropical and subtropical belt as identified approximately by mean annual rainfall and associated vegetation lies between the 125 and 500 mm isohyets, with a mean annual temperature between 18 and 30°C. Below 125 mm mean annual rainfall is the Extreme Arid of desert (' 50mm) and subdesert (50 to 125 mm), and above 500 m to 1000 mm is the mesic or intermediate rainfall zone. De Martonne's indices for the Arid Zone as defined above has a range of 3 to 18. The northern Pilbara as exemplified by the longterm records from Marble Bar is 9.1 near the middle of the scale for the tropical-subtropical arid zone. Similar indices are expressed by equivalent homoclimes elsewhere in the world:

Aridity Index	NORTHERN HEMISPHERE	Aridity Index	SOUTHERN HEMISPHERE
10.1	Nazas (Mexican Arid Plateau)	11.7	Catamarca (NW Argentina)
10.1	Cumana (Venezuela coast)	11.0	Eremutua (SWA/Namibia, Africa)
9.6	Hombori (W. Sahel Zone, Mali)	10.5	Messina (Limpopo Valley, S. Africa)
8.6	Kassala (E. Sahel Zone, Sudan)	10.1	Tulear (SW Madagascar coast)
9.6	Bhuj (NW Indian arid)	9.1	Marble Bar (NW Australia)

The longterm seasonal climatic patterns for Marble Bar and its world homoclimes are shown in Figure 4.10.

Steppes are cold semi-desert shrublands which occur polewards of the tropical-subtropical deserts, and are identified by having one or more months with mean temperatures of 6°C or less (Miller 1953, Stocker 1964). A comparative analysis of Australian and Argentinian climates is presented by Prescott *et al.* (1952).

Controls of Climate

As with the greater part of arid continental Australia, the climate of the Pilbara region is controlled largely by the seasonal north and south shift of the midlatitude (subtropical) belt of high pressure anticyclonic Trade Wind air masses, and their interaction with rain-bearing tropical or polar cyclonic low pressure systems that develop on either side of them.

In response to the solar control of high sun and low sun thermal conditions there is a seasonal shift of these main pressure belts equatorwards in winter and polewards in summer, though Trade Wind conditions with their subsiding dry air masses continue to recur in alternation between each cyclonic disturbance.

During high sun conditions in summer a series of continental heat lows (monsoonal depressions or troughs) develop across the Top End and these result in the build up of convectional thunderstorm rains which are local and patchy in occurrence. More widespread rains result from incursions of equatorial moisture bearing air from the NW across the Timor Sea and together these climax in January and February. From mid-summer to autumn tropical cyclones (hurricanes) develop over the Timor Sea and travel in a SW direction then recurve to the SE. Four out of ten of these cross the coast between Onslow and Broome and bring violent winds and flood rains. Rain from this source peaks in March.

With the return of cooler low sun conditions the heat lows dissipate, the pressure belts shift north and the Trades reassert their dominance, but now occur in alternation with far reaching polar cyclonic fronts which bring winter stratus cloud and some rains from the SW mainly between May and July (as shown by the subordinate winter rain convexity in the Marble Bar climograph). From August until November the Trade's aridity prevails until the buildup of heat entrains the development of successions of convective storms and tropical cyclones again (Figure 2.3).

Elements of Climate

Cloud Cover

The degree of cloud cover and its occurrence daily and seasonally directly affects radiation and insolation values and thus the ranges of diurnal temperature variations and evaporation, as well as air and ground moisture content.

The more complete and lower the cloud cover the greater the damping effect it imposes on radiation, temperature and evaporation values whilst increasing the moisture factor. The less the cloud cover, especially where afternoons and nights are clear, the greater are the ranges and extremes of the above parameters resulting in increasing desiccation.

Cloud cover over the region is relatively sparse throughout the year, but is greatest during the rains period from December to March and least in the dry season from July to November. Cloud cover is most in the afternoons and least at night and in the mornings when it is usually clear. Longterm daily records from nearby Marble Bar shows that on a monthly basis the afternoon averages approach only half sky cover values between January and March (see Table 2.1, Figure 2.3).

Table 2.1. Average Cloud Cover (octas). (Data from Australian Bureau of Meteorology 1972, Table 16).

	J	F	M	A	M	J	J	A	S	O	N	D	Yr.
9 am	2.4	2.7	2.0	1.9	2.1	1.8	1.4	0.9	0.7	0.7	1.1	1.5	1.6
3 pm	3.8	3.6	3.3	2.5	2.3	1.8	1.3	1.1	1.0	1.5	2.5	3.1	2.3

Radiation

The average monthly total solar radiation received at the earth's surface in the northern Pilbara in midsummer is 600 cal. cm^{-1} day^{-1} (January) and between 350 and 400 cal. cm^{-1} day^{-1} in midwinter (July) (Gentilli 1971).

Temperature

The thermal regime in the northern Pilbara is hot to extremely hot (torrid) for three quarters of the year, with large diurnal extremes in temperature range every month. Four thermal seasons are experienced in the region as depicted by Figure 2.3.

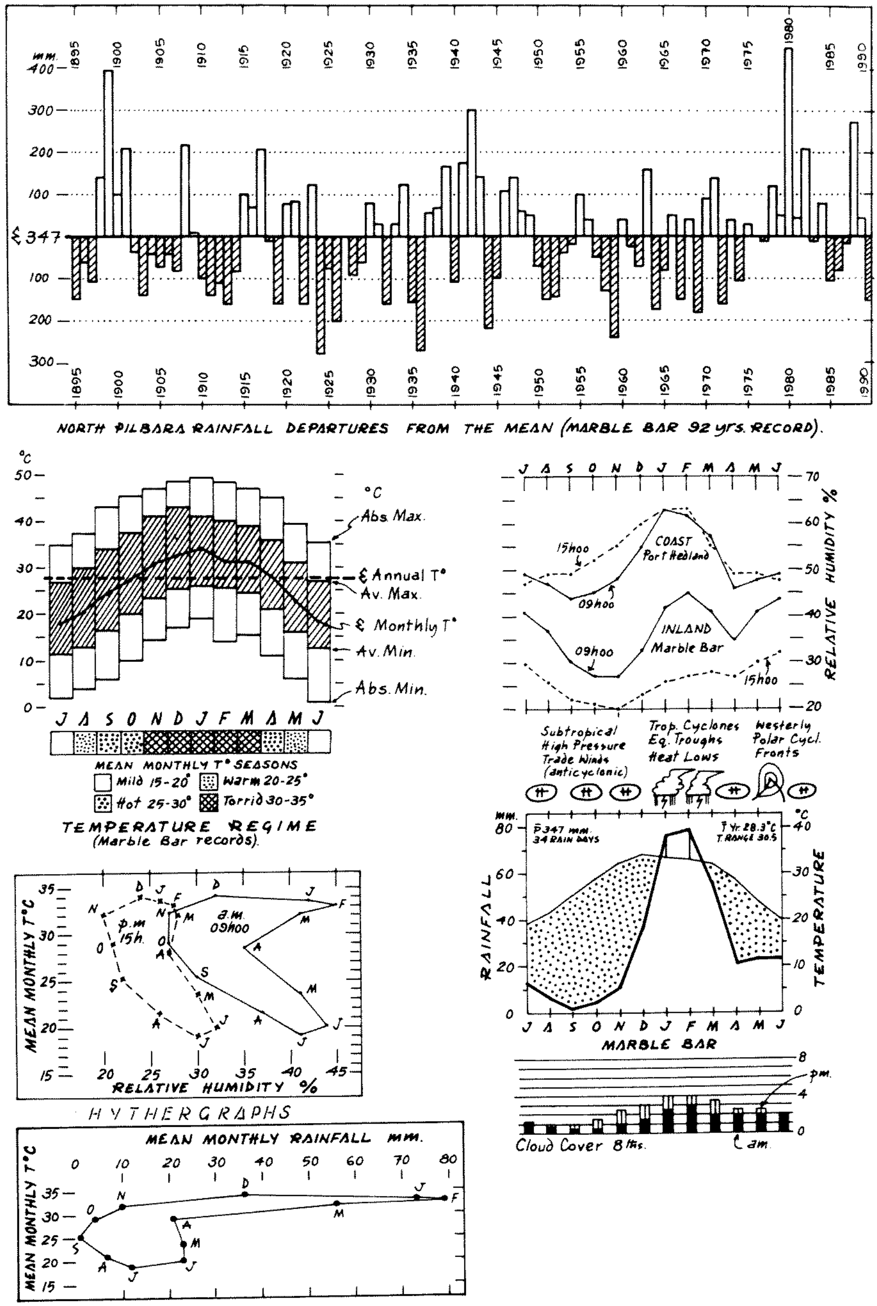

Figure 2.3 Climographic synthesis of inland temperature and moisture relations in the north Pilbara Region.

Due to the damping effect of the sea on temperatures the hottest month at the coast at Port Hedland (March 37°C mean max.) is three months later than it is inland at Marble Bar (December 42°C mean max.). Temperature increases inland from the coast with the hottest belt parallel to the coast running through Marble Bar which has the highest average maximum temperature for any month in Australia. At Marble Bar 38°C (100°F) has been reached or exceeded on each day of the months November to March and on 29 days of April and October (Australian Bureau of Meteorology, 1972). Temperatures of 38°C and higher have been logged at Marble Bar for as many as 161 consecutive days (see Table 2.2), and an absolute maximum of 49.2 °C has been recorded in January. Valleys enclosed by hills are the hottest sites, and the coldest as well.

Table 2.2. Number of days on which temperature reaches or exceeds 44°C at Marble Bar. (Data from Australian Bureau of Meteorology 1972)

	J	F	M	A	M	J	J	A	S	O	N	D	Yr
Av. No.	10	7	3	0	0	0	0	0	0	1	6	10	37
Highest No.	24	29	22	3	0	0	0	0	0	5	19	18	64

Frosts are recorded in June from Marble Bar but the Abydos 19 year record consistently showed an average of one frost a year either in June, July or August. Frost occurrence and frequency is enhanced by downslope drainage of cold air at night to low ground, and also results from incursions of cold air from the south following the passage of the stronger, far reaching polar cyclonic depressions. Frosts have been recorded as close as 8 km from the coast at Anna Plains (Australian Bureau of Meteorology 1972).

The annual temperature range of 30.5°C is less significant than the huge diurnal fluctuations that cannot be adequately conveyed by the mean values. The cloudless skies at night allow for rapid loss of heat by outward radiation after sunset resulting in a fast drop in temperature to below 20°C; clear mornings enables the heat to rapidly intensify close to or past 38°C by midday, and to over 40°C in the afternoons. The mean diurnal range of temperature extremes is between 30°C and 37°C in every month of the year, with the greatest contrasts in September (Australian Bureau of Meteorology 1972). During the field survey in March 1988 day temperatures in the two middle weeks of the month rose to 48°C every day and dropped to 15 or 16°C at night.

Wind

East to SE winds prevail throughout the year in both the mornings and afternoons. However from September to December NW to W winds are more frequent, and from January to February there are more NE than SE winds. As experienced in March 1988 during the field survey the N wind from off the sea is unpleasantly hot and humid. By comparison the easterly winds from the interior are fresh and revitalizing until about midday after which they become torrid.

The highest percentage of winds over 30 km/h occur in March, May, and from August to September in the mornings (highest in September), and on May and October to November in the afternoons. April, June, July and September rarely have strong afternoon winds. Calm conditions prevail between June and January in the mornings and during the afternoons of April and from August to October (Australian Bureau of Meteorology 1972 Table 18g).

Winds associated with the passage of tropical cyclones often reach velocities higher than 150 km/h. The highest wind velocity recorded in Australia was a 218 km/h gust at Onslow during a cyclone (Lourensz 1981). March has the highest monthly frequency of cyclones crossing the NW coast followed by January (Lourensz 1981).

As a cyclone approaches from the sea, winds are at first easterly and become westerly after it has passed inland. "The wind changes direction through north if the storm passes to the west of the observer, and through south if it passes to the east" (Australian Bureau of Meteorology 1972, Lourensz 1981).

Precipitation

All life depends on moisture and nowhere is it more strikingly displayed than in the arid and extreme arid regions where a seemingly dead landscape is resurrected to burgeoning life by the incidence of rain. Most precipitation in the region is in the form of rain, but dews occur close to the coast and seasonally inland after rains. No fog precipitation has been recorded from the region.

The longterm rainfall pattern shows a late summer wet season of three months from January to March followed by nine months dry season from April to December. A small and sometimes significant secondary rain peak occurs in May and June from the stronger far reaching polar cyclonic fronts. The duration and intensity of the alternating wet and dry seasons over the longterm in the region, and in comparable homoclimes elsewhere, are depicted by means of Gaussen climographs (Bagnouls & Gaussen 1957) in Figures 2.3 and 4.10.

Though the rainfall is strongly seasonal it is extremely erratic; hence totals for individual months and annual amounts vary greatly from the average figures. Over the longterm each month of the year has recorded no rain, and annual totals vary from a minimum of 72 mm (1924) to 797 mm (1980) and annual total number of rain days ranges from 12 to 60.

The great year to year variation in annual rainfall is well illustrated by a histogram for the 92 year record from Marble Bar showing the alternating succession of consecutive high and low rain years (Figure 2.3). Up to six consecutive drought years occur as a group and up to four of high rain years. However where large groups of consecutive drought years are broken by only one or two years of only 100 mm or less above the mean these are likely experienced in the field as 20 or 25 year long drought cycles as exemplied by the 1930 to 1975 period (Figure 2.3).

In a region of massive cumulonimbus thunderstorm generation and of tropical cyclones extremely heavy rains of short duration are characteristic. In the Marble Bar heat belt major effective rains of more than 20 mm falls occur on average five times a year accounting for 75 to 80% of the total rainfall (Beard 1975). However from 60 to over 200% of the mean annual rainfall total can occur from a single storm, particularly from torrential cyclonic rains.

Whim Creek with a mean annual total of 350 mm, near the coast between Roebourne and Port Hedland, was hit by a tropical cyclone in April 1898 which dropped 737 mm of rain in less than 24 hours, and 910 mm by 36 hours! In the Marble Bar heat belt inland from the coast a total of 337 mm (97% of the total) fell in February 1980 resulting in river floods reaching the highest levels ever recorded from Hillside on the Shaw River (Max Richardson, pers. comm.).

At the end of March 1988 during the fieldwork for this survey a total of 233 mm fell mainly within a 17 hour period at Woodstock homestead from an intense tropical trough. Torrential rain fell for hour long bursts from nimbostratus cloud followed by lulls of 15 to 20 minutes. Winds were force 6 from the NE veering later to the SE. The creek floods peaked on the second day and dropped radically on the third day when rain started petering out after 14hrs of heavy downpours the previous day.

Thunder is heard on average only on 20 to 30 days of the year, and hail is an infrequent form of precipitation though large stones are to be expected because of the parched air (Australian Bureau of Meteorology 1972).

No fog or mist forms of precipitation, nor snow, is reported from the area, though valley radiation fogs may occur in and adjacent to the Gorge Ranges unit in the autumn. Dew and guttation of water by plants was experienced in April and May after flood rains had saturated the soil profile on 28 and 29 March 1988. Their occurrence throughout the year is not recorded, but it should be possible to determine when dew point is reached by using hygrometer readings with tables. Dew is important as a source of moisture to plant and animal life in the extreme arid regions such as the Atacama, Namib and Sahara Deserts. In the latter dews occur within 20 km of the coast and a 4 km radius of oases (Cloudsley-Thompson & Chadwick 1964).

In practise the growing season for native pastures is best represented by summing all periods of growth during the year, which occur when rainfall equal to or greater than 0.4 of evaporation (from a free water surface) occurs for at least one week. Summing the periods of growth based on this moisture relationships there are 10 growing weeks in the Marble Bar heat belt inland of the coast. Here January 27 is the median date beginning the first growing period, and March 8 the beginning of the main growing period (Australian Bureau of Meteorology 1972).

Drought

The bulk of the rainfall occurs in the hottest part of the year, but these rains may fail part, or sometimes the whole of the growing season. Over the longterm there are 9 to 10 months of drought as depicted by the Gaussen climograph (Figures 2.3 and 4.10). The isolines drawn for drought incidence (rainfall deficiency) for the whole continent puts the Marble Bar heat belt in the high incidence class (Index 0.6-0.7), with three increasingly severe categories still above it (Plate 26 in Australian Bureau of Meteorology 1983b).

Frequency of drought of various lengths expressed as percentages of the total number occurring during the period of record shows the following pattern at Marble Bar with coast data from Port Hedland for comparison (Table 2.3).

Table 2.3. Percent of drought periods of particular duration. Data from Table 17 Australian Bureau of Meteorology (1972).

Months duration	2	3	4	5	6	7	8	9	10	11	12	14	16	18	20	22	No. yrs rec.
Marble Bar	100	97	88	72	50	41	30	20	13	8	5	3	3	3	2	0	66
Port Hedland	100	100	97	83	61	49	37	17	12	7	3	2	0				60

Relative Humidity

The seasonal relative humidity fluctuations in the Marble Bar heat belt inland of the coast is closely correlated with rainfall occurrence in summer and winter. The striking feature exhibited by the higher *morning* humidity curve for Marble Bar are the bimodal peaks in midsummer and midwinter, and the midwinter unimodal peak for the lower afternoon values. These peaks relate to the more effective moisture status occurring under cooler temperature conditions between May and July. By contrast humidity conditions on the coast at Port Headland are much higher year round, higher in the afternoons from sea breezes with only a slight bimodality from a small peak in midwinter (Figure 2.3, Table 2.4).

Table 2.4. Percentage Relative Humidity values for 9am and 3pm inland and at the coast. Data from Bureau of Meteorology (1972).

	J	F	M	A	M	J	J	A	S	O	N	D	
Marble Bar	42	**45**	41	35	41	**44**	41	37	30	27	27	32	9 am
	26	27	**28**	27	30	**32**	30	26	22	21	20	23	3 pm
Port Hedland	**63**	62	57	46	48	**49**	**49**	47	44	45	48	55	9 am
	63	**63**	56	49	49	48	47	49	49	52	55	60	3 pm

Evaporation

The total annual average evaporation from a free water surface in the region is about 3700 mm (Australian Bureau of Meteorology 1983a, measured by Class A Pan with bird guard). This exceeds the mean annual rainfall by a factor of 10.7. Evaporation is highest in January (330 mm) and lowest in July (127 mm).